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Evidence for True Polar Wander of Ceres

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Abstract

The true polar wander (TPW) of Ceres allows to explain the origin of several surface features, as well as a prominent crustal density anomaly, under a common scenario. The inferred complex reorientation of Ceres implies a weak rotational coupling between crust and mantle, with a buried water ocean as one of the possible mechanisms. The remnant of a narrow paleo-equatorial ridge, and a possible remnant rotational bulge, suggest some similarities with Iapetus.

1. Introduction

Among all the geophysical processes taking place on a large body, the true polar wander (TPW) connects in an unique fashion the changes to the interior density, typically responsible for triggering the TPW, to changes on the surface of the body, leading to tectonic patterns caused by complex crustal stresses during the reorientation of the body. The exploration of Ceres by the Dawn mission has allowed to determine that Ceres underwent TPW early in its history [7], and this allows to collect under the common scenario a wide range of observations which would otherwise appear as uncorrelated.

2. Equatorial Density Anomaly

By applying the Global Gravity Inversion (GGI) method [6] to the shape and gravity field of Ceres, we find a range of interior structure models which are compatible with the observations. These interior solutions show a prominent positive density anomaly approximately aligned with the equator, in the region of Ahuna Mons [7]. The characteristics of this density anomaly make it an excellent candidate for triggering the TPW.

3. Paleo-Equatorial Ridge

By performing a statistical analysis of the topography along great circles, averaged over narrow bands (1° from reference great circle), we can search for a

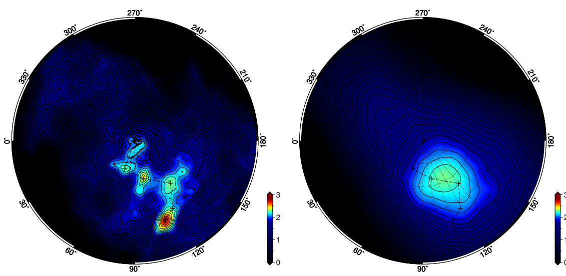

Figure 1: Left panel: paleo-pole at 54°N, 111°E and its path to the current pole of Ceres. Right panel: candidate pole of the remnant bulge of Ceres. Both plot regions extend form latitude 40°N to the current pole. The color scale is the significance in std. dev. units.

remnant narrow paleo-equatorial ridge. In Figure 1 we show a clear statistical excess of approximately 2.8σ for a paleo-equatorial ridge corresponding to a paleo-pole at 54°N, 111°E. A profile of the equatorial ridge is presented in Figure 2, where it is compared with the much more prominent Iapetus equatorial ridge. The ridge of Ceres is at least one order of magnitude lower, but presents similar characteristics in terms of width and profile. Also the Ceres ridge appears to have formed on a possible remnant bulge, see Section 4. The equatorial ridge likely formed from compressional stresses at the equator during TPW, due to a relatively thick crust, leading to thrust faults in the equatorial band. The statistical excess of Figure 1 suggests a path of the pole which appears indirect, *S*-shaped. The complex apparent evolution of the TPW, along with the dual-component of the density anomaly, could indicate a weak rotational coupling between crust and mantle of Ceres.

4. Remnant Bulge

During TPW, it is possible that the crust will not adjust perfectly to the new equilibrium shape, and form a remnant bulge [5]. As such, the pole of a remnant bulge is typically expected to be between the paleo-pole and the current pole of a body. The statistical analysis of Section 3 can also be employed to look

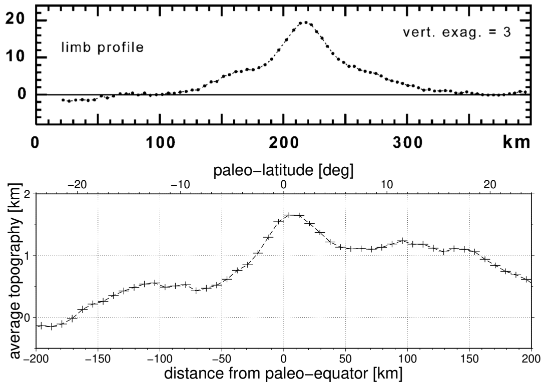

Figure 2: Top panel: limb profile of Iapetus and its prominent equatorial ridge, adapted from [3]. Bottom panel: average topography of Ceres relative to the average reference geoid. Topography averaged over 1° latitude bands. Plots have the same horizontal scale.

for a candidate remnant bulge, simply by increasing the band width (20° from reference great circle). In Figure 1 we show the resulting distribution, with the candidate pole of the remnant bulge located exactly between the paleo-pole and the current pole of Ceres, supporting the TPW scenario. Because of its large width, the remnant bulge appears at the base of the narrow paleo-equatorial ridge, see Figure 2.

5. Tectonic Patterns

The tectonic patterns are very sensitive to the actual pole path [4], so a good match between the expected tectonic patterns and the observed crustal fractures on Ceres further supports the indirect path of the pole in Figure 1 and the TPW scenario. For Ceres we show that the predicted tectonic patterns are in good agreement with the observed crustal fractures Samhain Catenae and Uhola Catenae [7]. Additionally, the expected fractured region extends to Ahuna Mons, thus providing a mechanism for its formation from the density anomaly material at depth.

6. Occator Fractures

Many of the fractures within the Occator crater appear to be aligned with the direction of the paleo-equator. Since the crater formed over the paleo-equatorial ridge, see Figure 3, it is possible that this preferential orientation of the fractures is due to an interaction between the pre-existing paleo-equatorial ridge and the formation Occator crater. Floor fractures are also present in the Azacca crater [2], near the edge of the region experiencing extensional stresses during TPW.

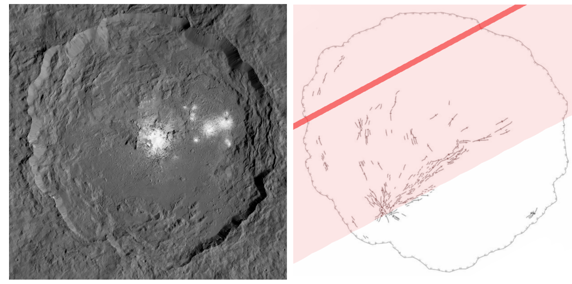

Figure 3: Occator crater (left) and fracture map (right, adapted from [1]). The paleo-equator of Ceres crosses the crater, with the thin and thick red bands indicating respectively the approximate center and width of the paleo-equatorial ridge. Many fractures appear aligned with the paleo-equatorial direction.

Acknowledgements

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